

What is claimed is:

1. A method for reducing NOx from an exhaust gas, comprising autothermally heating the exhaust gas using one or more hydrocarbons in the presence of NH<sub>3</sub>, HNCO or a combination thereof, wherein the autothermal heating is under conditions effective for reducing the NOx autocatalytically.

2. The method of claim 1, wherein the NOx in the exhaust gas is reduced nearly stoichiometrically by as much as 80-90%.

3. The method of claim 1, wherein the NOx in the exhaust gas is selectively reduced by as much as about 99%.

4. The method of claim 1, wherein the NOx in the exhaust gas is reduced to a level in the range of about 10-200 ppm.

5. The method of claim 1, wherein NH<sub>3</sub> and HNCO together are in the range of about 0.5-2.0 molar ratio with respect to the NOx in the exhaust gas.

6. The method of claim 1, wherein the exhaust gas temperature is initially in the range of 900-1600°F and the exhaust gas initially contains O<sub>2</sub> in the range of about 2-18%.

7. The method of claim 1, wherein the autothermal heat release is initiated by autoignition of hydrocarbon(s) in the exhaust gas.

8. The method of claim 1, wherein the autocatalytic reactions are self-sustained in the autothermally heated exhaust gas even when a portion of the heat released is recovered by heat transfer surfaces.

9. The method of claim 1, wherein the heat release is equivalent to a uniform adiabatic increase of about 50-500°F in the exhaust gas temperature.

10. The method of claim 1, wherein the exhaust gas is heated within about 0.02-1.5 seconds to a final temperature.

11. The method of claim 1, wherein the exhaust gas is heated to a final temperature in the range of about 1400-1550°F.

12. The method of claim 1, wherein the exhaust gas contains at least about 1 % O<sub>2</sub> at a final temperature in the range of about 1400-1550°F.

13. The method of claim 1, wherein residual concentrations of hydrocarbons, CO, NH<sub>3</sub> and HNCO are depleted substantially at a final temperature in the range of about 1400-1550°F.

14. The method of claim 1, wherein the CO is oxidized below a residual concentration of about 2000 ppm.

15. The method of claim 1, wherein the CO is oxidized below a residual concentration of about 500 ppm.

16. The method of claim 1, wherein the residual concentration of CO is maintained at a level below about 500 ppm by controlling a final exhaust gas temperature in the range of about 1400-1550°F.

17. The method of claim 1, wherein the residual concentration of NH<sub>3</sub> is maintained at a level below about 20 ppm by controlling a final exhaust gas temperature in the range of about 1400-1550°F.

18. The method of claim 1, wherein the residual concentrations of CO and NH<sub>3</sub> are depleted together autocatalytically in the exhaust gas at a final temperature in the range of about 1400-1550°F.

19. The method of claim 1, wherein the final temperature is controlled in the range of about 1400-1550°F to maintain the residual CO concentration below about 50 ppm while depleting the residual NH<sub>3</sub> below about 2 ppm.

20. The method of claim 1, wherein the hydrocarbon(s) comprise material(s) selected from the group consisting of hydrocarbon mixtures such as natural gas, liquefied petroleum gas, alcohols, gasoline, diesel fuel, aviation turbine fuel, various oxygenated hydrocarbons, hydrocarbon amines or any fraction of such mixtures, including purified components such as carbon monoxide, methane, propane, methanol and ethanol, either as liquids or vapors.

21. The method of claim 1, wherein the hydrocarbon(s) are introduced substantially throughout a cross-section or around a perimeter of the exhaust gas flowpath using one or more nozzles, including a multiplicity thereof.

22. The method of claim 1, wherein the hydrocarbon(s) are introduced as liquid drops with diameters in the range of about 20-500 microns.

23. The method of claim 1, wherein the hydrocarbon(s) are introduced in the exhaust gas using a carrier or atomizing gas such as steam, compressed air, pressurized exhaust gas, gaseous or vaporous hydrocarbon(s) or any gaseous or vaporous NH<sub>3</sub> compositions.

24. The method of claim 1, further comprising the steps of measuring a final temperature at one or more locations throughout the cross-section of the exhaust gas flowpath and controlling

the amount of introduced hydrocarbon(s) to maintain the measured temperature(s) at a level in the range of about 1400-1550°F.

25. The method of claim 24, further comprising the step of measuring a final CO concentration at one or more locations throughout the cross-section of the exhaust gas flowpath downstream from the temperature measurement(s).

26. The method of claim 25 further comprising the step of using the final CO measurement(s) to verify a level of CO depletion corresponding to the final temperature(s) for controlling the introduction of hydrocarbon(s).

27. The method of claim 1, further comprising the step of generating  $\text{NH}_3$ ,  $\text{HNCO}$  or a combination thereof by vaporization, decomposition, or catalytic conversion of reductant(s) which comprise any of the material(s) selected from the group consisting of  $\text{NH}_3$ ,  $\text{HNCO}$ , cyanuric acid or a tautomer of cyanuric acid, urea, decomposition products of urea, compounds which decompose to produce  $\text{NH}_3$  as a byproduct, ammonium salts of organic acids, hydrocarbon amines, or combinations of the foregoing, whether pure compounds or mixtures, as solids, liquid melts, emulsions, slurries or solutions in water, alcohols, hydrocarbons, or oxygenated hydrocarbon solvents.

28. The method of claim 27, wherein the  $\text{NH}_3$ ,  $\text{HNCO}$  or a combination thereof are generated prior to the introduction of hydrocarbon(s).

29. The method of claim 27, wherein the  $\text{NH}_3$ ,  $\text{HNCO}$  or a combination thereof are generated after the introduction of hydrocarbon(s).

30. The method of claim 27, wherein the  $\text{NH}_3$ ,  $\text{HNCO}$  or a combination thereof are generated concurrently with the hydrocarbon(s).

31. The method of claim 27, further comprising the step of injecting reductant(s) directly to vaporize or decompose in the exhaust gas.

32. The method of claim 31, wherein the reductant(s) are injected prior to the introduction of hydrocarbon(s).

33. The method of claim 31, wherein the reductant(s) are injected after the introduction of hydrocarbon(s).

34. The method of claim 31, wherein the reductant(s) are injected concurrently with the introduced hydrocarbon(s) as mixtures, solutions, emulsions, slurries, atomizing gases, atomized liquids or combined chemical structures.

35. The method of claim 31, wherein the reductant(s) comprise a concentrated aqueous solution consisting of  $\text{NH}_3$ , urea or combinations thereof in water containing dissolved nitrogen in the range of about 15-30% by weight.

36. The method of claim 31, further comprising the steps of measuring baseline NOx levels in the exhaust gas with respect to an operating condition of combustion equipment that produces the exhaust gas and controlling the amount of reductant(s) injected to maintain a level of NOx reduction or a final NOx level in the exhaust gas throughout the operating range of the combustion equipment.

37. The method of claim 36, further comprising the step of monitoring an operating condition of the combustion equipment to provide a basis for estimating the baseline NOx emissions throughout the operating range of the combustion equipment, either continuously or frequently.

38. The method of claim 37, wherein the amount of injected reductant(s) is controlled to generate  $\text{NH}_3$  and HNCO together at a level in the range of about 0.5-2.0 molar ratio with respect to the baseline NOx depending on a measurement of the operating condition for the combustion equipment.

39. The method of claim 31, further comprising the step of measuring a final NOx level at one or more locations throughout the cross-section of the exhaust gas flowpath downstream from the autothermal heating and any temperature measurement(s) used to control the introduction of hydrocarbon(s).

40. The method of claim 39, further comprising the step of using the final NOx level(s) to verify the effectiveness of selective NOx reduction corresponding to an amount of introduced  $\text{NH}_3$  and HNCO or an amount of reductant(s) injected to generate  $\text{NH}_3$ , HNCO or a combination thereof.

41. The method of claim 40, further comprising the step of controlling the amount of introduced  $\text{NH}_3$  and HNCO or the amount of reductant(s) injected to maintain a final NOx level in the exhaust gas.

42. The method of claim 1, further comprising either alternative step of preheating or precooling the exhaust gas to a temperature in the range of about 900-1600°F before the introduction of hydrocarbon(s).

43. The method of claim 42, wherein the exhaust gas is preheated or precooled to a temperature in the range of about 1050-1600°F so that the exhaust gas is heated autothermally in 0.02-1.0 seconds to a final temperature in the range of about 1400-1550°F by a heat release equivalent to an adiabatic increase of about 50-350°F effective for enhancing the selectivity of autocatalytic NOx reduction.

44. The method of claim 42, wherein the exhaust gas is preheated or precooled to a temperature in the range of about 1200-1600°F so that the exhaust gas is heated autothermally in 0.02-0.5 seconds to a final temperature in the range of about 1400-1550°F by a heat release equivalent to an adiabatic increase of about 50-200°F effective for enhancing the selectivity of autocatalytic NOx reduction.

45. The method of claim 1, further comprising the step of combusting a supplemental fuel to preheat the exhaust gas in the temperature range of about 900-1350°F.

46. The method of claim 45, wherein a supplemental fuel is combusted directly in the exhaust gas.

47. The method of claim 1, wherein the introduced hydrocarbon(s) are mixed substantially uniformly before the appearance of a visible chemiluminescence.

48. The method of claim 1, further comprising the step of recovering heat from the autothermally heated exhaust gas using heat transfer surfaces between the exhaust gas and the heat recovery fluid.

49. The method of claim 48, wherein heat is recovered from the exhaust gas to heat another fluid such as steam, water, combustion air or a petrochemical composition.

50. The method of claim 48, further comprising the step of cracking a petrochemical composition.

51. The method of claim 48, further comprising the step of generating steam.

52. The method of claim 51, further comprising the steps of coupling the steam to a turbine and operating machinery or generating electricity.

53. The method of claim 1, further comprising the step of generating NH<sub>3</sub> breakthrough from a previous noncatalytic method for selectively reducing NOx, the method further comprising the noncatalytic reduction of NOx at temperatures above 1600°F prior to the autothermal exhaust gas heating and autocatalytic NOx reduction.

54. The method of claim 1, further comprising the step of catalytically reducing a portion of the remaining NOx using a solid catalytic surface and additional generation of NH<sub>3</sub>, HNCO, or combinations thereof after the autothermal exhaust gas heating.

55. The method of claim 54, wherein the exhaust gas is heated autothermally to control the temperature for the subsequent catalytic NOx reduction using a solid catalytic surface.

56. The method of claim 54, wherein the first stage of gas-phase autocatalytic NOx reduction lowers the inlet NOx level to the solid catalytic surface.

57. The method of claim 54, wherein the first stage of autothermal heating decreases exhaust gas contaminants such as hydrocarbons, soot, CO and particulate matter.

58. The method of claim 54, wherein the solid catalytic surface serves the dual purpose of decreasing the final NOx level and recovering a portion of the autothermal heat release.

59. A method comprising the steps of:

controlling the initial temperature and composition of an exhaust gas in the ranges of about 900-1600°F and about 2-18% O<sub>2</sub>, respectively, effective for autoignition of hydrocarbons;

controlling the introduction of hydrocarbons to autoignite and release heat autothermally effective for self-sustaining autocatalytic reactions under fuel-lean conditions wherein the exhaust gas contains at least 1% O<sub>2</sub> and is heated to a final temperature in the range of about 1400-1550°F;

introducing one or more reductants for NOx into the exhaust gas wherein NH<sub>3</sub>, HNCO or a combination thereof are generated from the reductant(s);

wherein NOx is reduced, and the NH<sub>3</sub>, HNCO and hydrocarbons, including any byproduct CO are depleted substantially.

60. A method for selectively reducing oxides of nitrogen in an exhaust gas using NH<sub>3</sub>, HNCO or a combination thereof while hydrocarbons(s) autoignite and heat the exhaust gas autothermally to a temperature in the range of about 1400-1550°F, substantially depleting residual concentrations of unburned hydrocarbons, CO, HNCO and NH<sub>3</sub>.